Multi-batch studies and accelerators jobs for collaborators

❖ **Status and plan for multi-batch studies**

❖ **The goal**: to get $\mathbf{2.5 \times 10^{13}}$ protons/cycle to NuMI, which implies $\mathbf{3.3 \times 10^{13}}$ protons accelerated to 120 GeV in MI ($\mathbf{0.8 \times 10^{13}} \rightarrow$ pbar target)

❖ **People presently involved**

Bob Z.
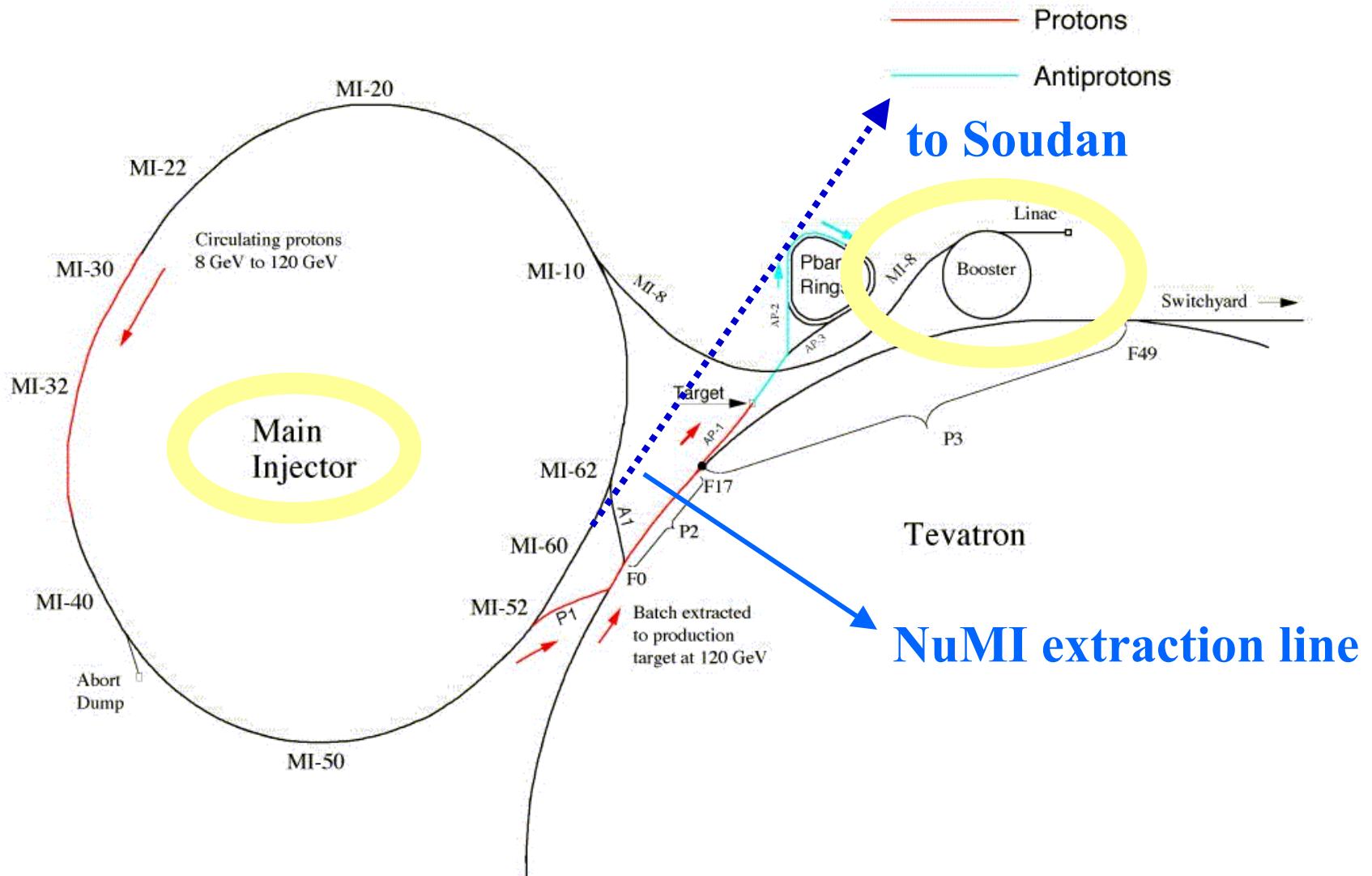
Alberto M., Bill F., Brajesh C., Dennis N., Sanjib M.

Dave C., Dave J.

Hyejoo K., Karen W.

❖ **Possible accelerators jobs for collaborators indicated by**

$\Rightarrow$

The accelerators

Accelerators main parameters

Booster

Circumference	2π×74.47 m	Harmonic Number	84
Injection kinetic energy	400 MeV	RF Frequency (Inj.)	37.77 MHz
Extraction kinetic energy	8 GeV	RF Frequency (Extr.)	52.81 MHz
Transition gamma	5.45	Cycle time	1/15 s

Main Injector

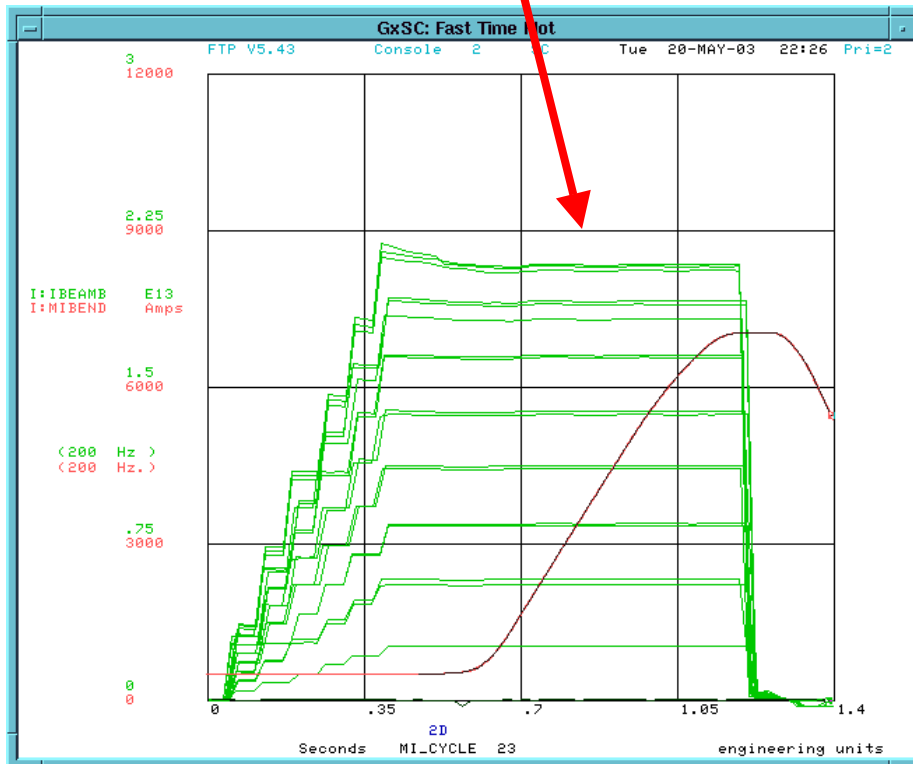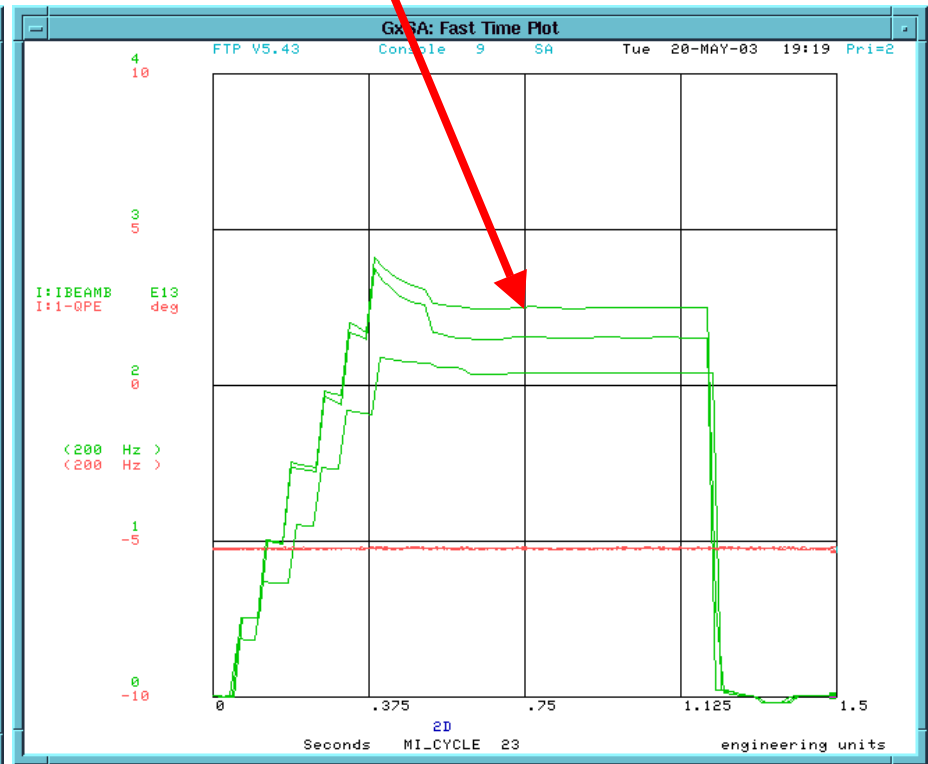| Circumference	3319.49 m	Harmonic Number	588 (7×84)
Injection momentum	8.88 GeV	RF Frequency (Inj.)	52.8 MHz
Peak momentum	150 GeV	RF Frequency (Extr.)	53.1 MHz
Transition gamma	21.8	RF Voltage	4 MV

Multi-batch status last year

March '02
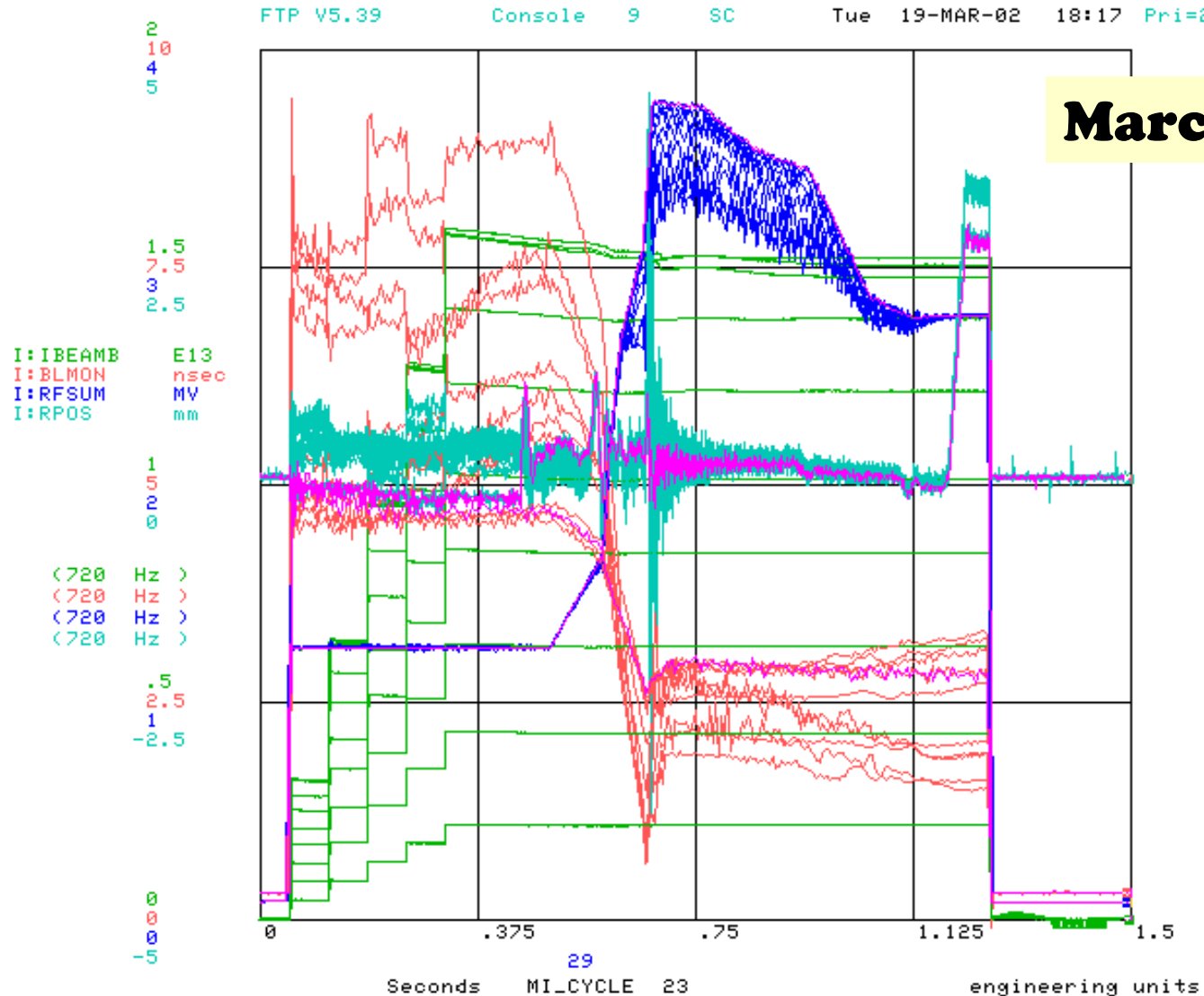
Restarting multi-batch operation in MI

May '03

6 batches, increasing Booster turns

6 batches, 14 Booster turns

Bunch-by bunch digital dampers
by Bill Foster

- Digital transverse and longitudinal bunch-by-bunch dampers have been prototyped and tested

- The system consists of beam signal pickups and relative kickers

- Final longitudinal kickers have been fabricated and are being installed during the shutdown

- A second generation signal processing board will be ready by the end of the shutdown

- Pickup signals digitized at 212 MHz, with 12 bit resolution

- Digital pipelined processing in field-programmable gate array logic

- Damper kicks digitally synthesized by a 424 MHz DAC

All-Coordinate Digital Damper
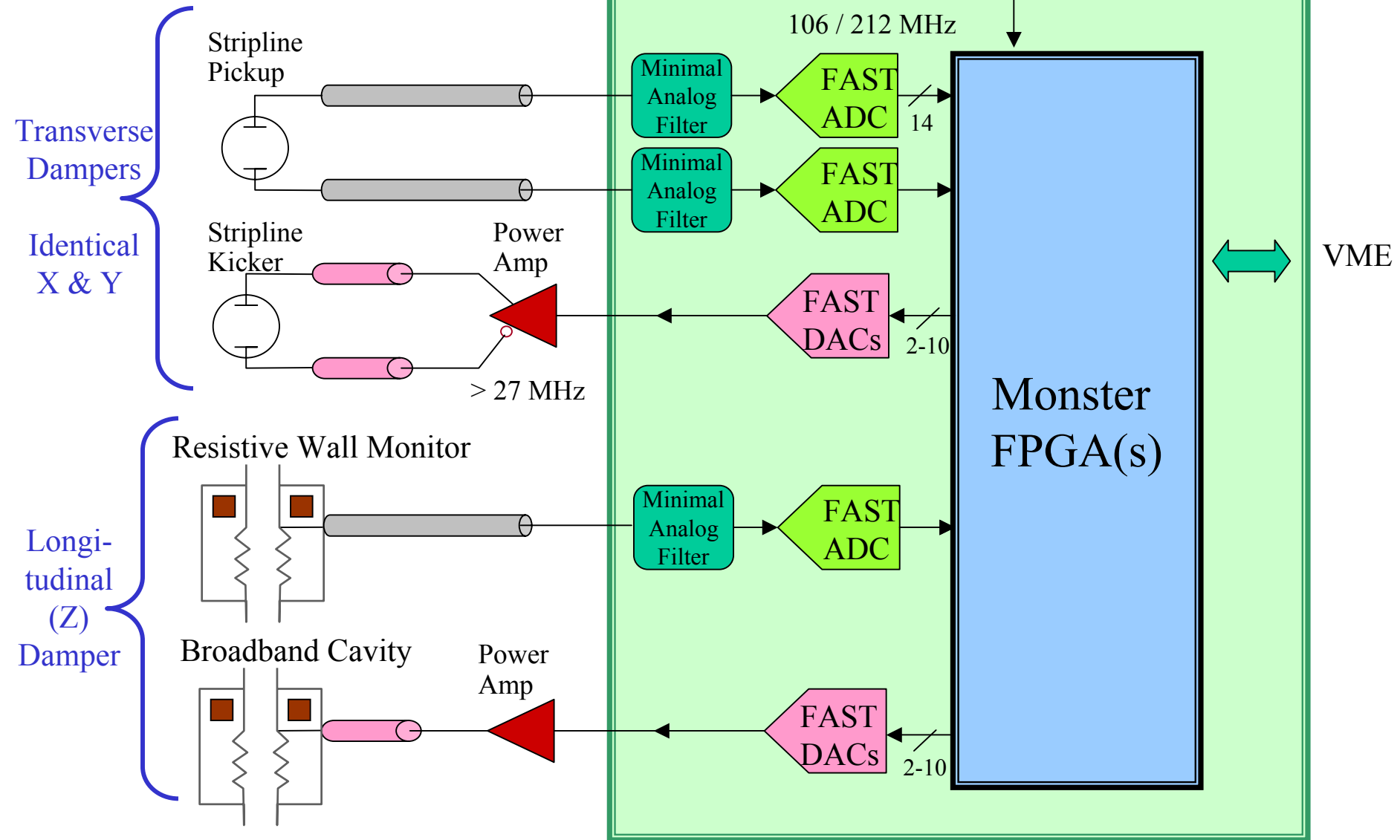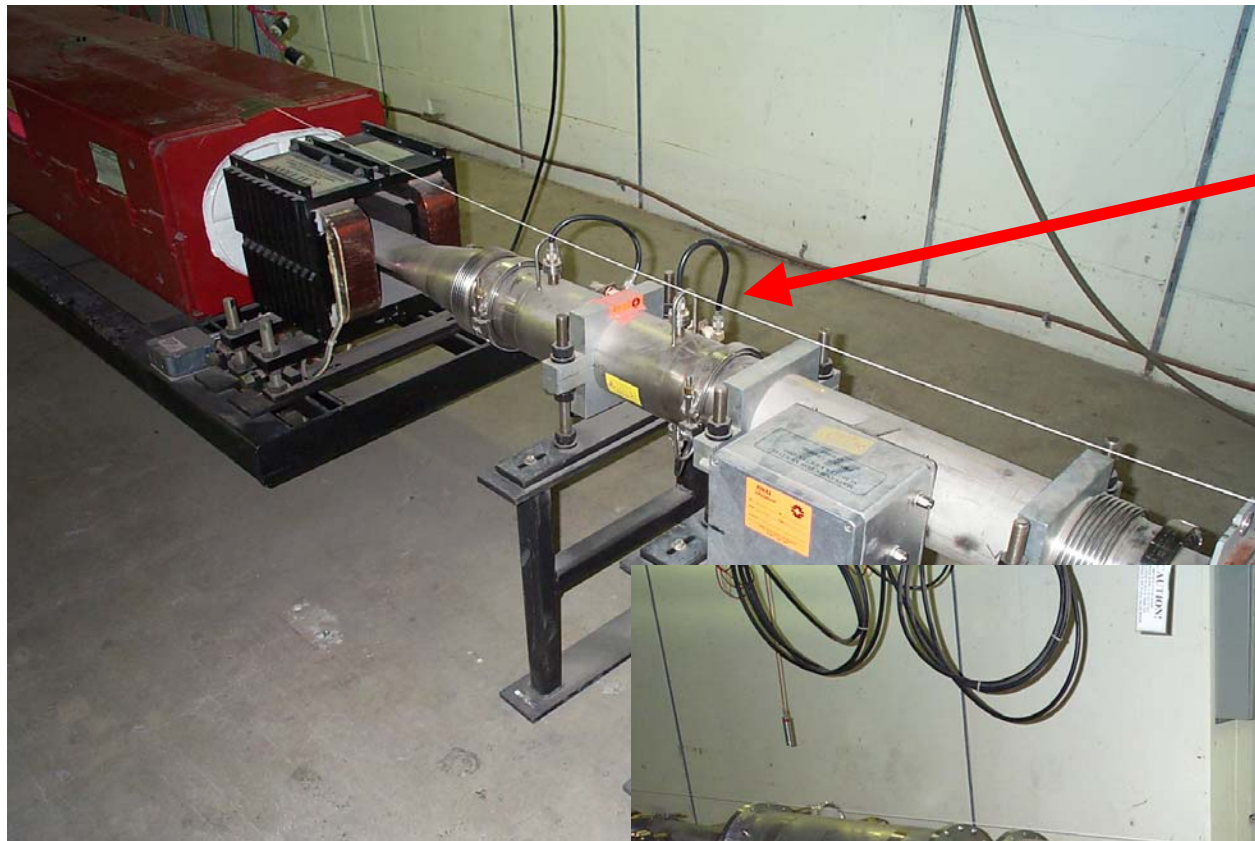
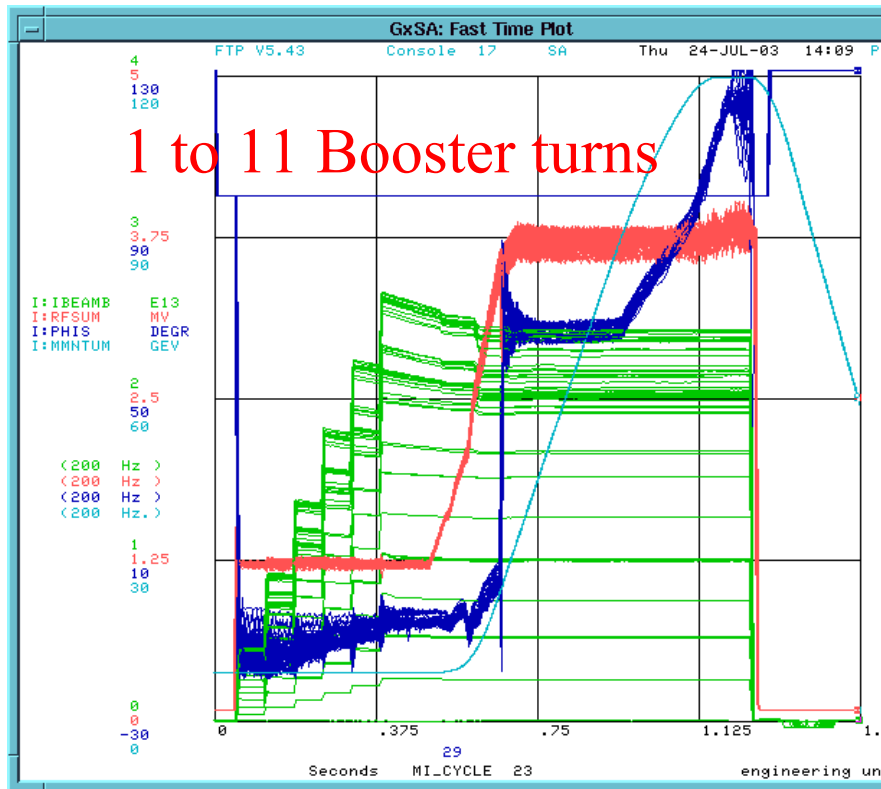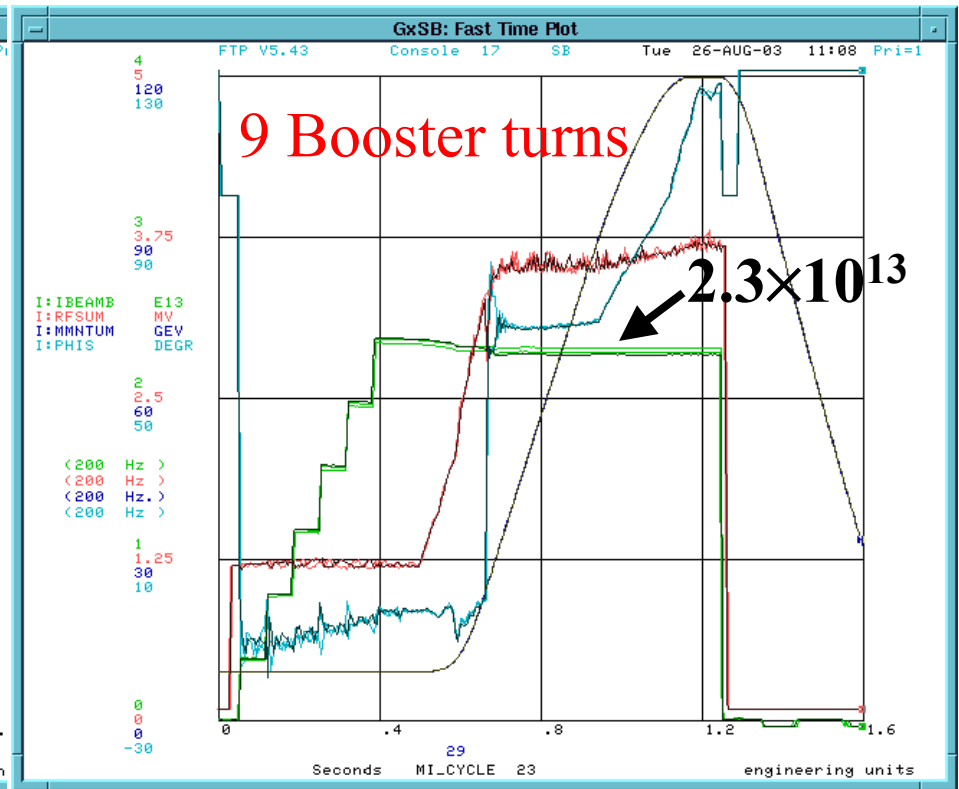Horizontal damper pickup

Longitudinal kickers

Multi-batch with and w/o transverse dampers

w/o dampers

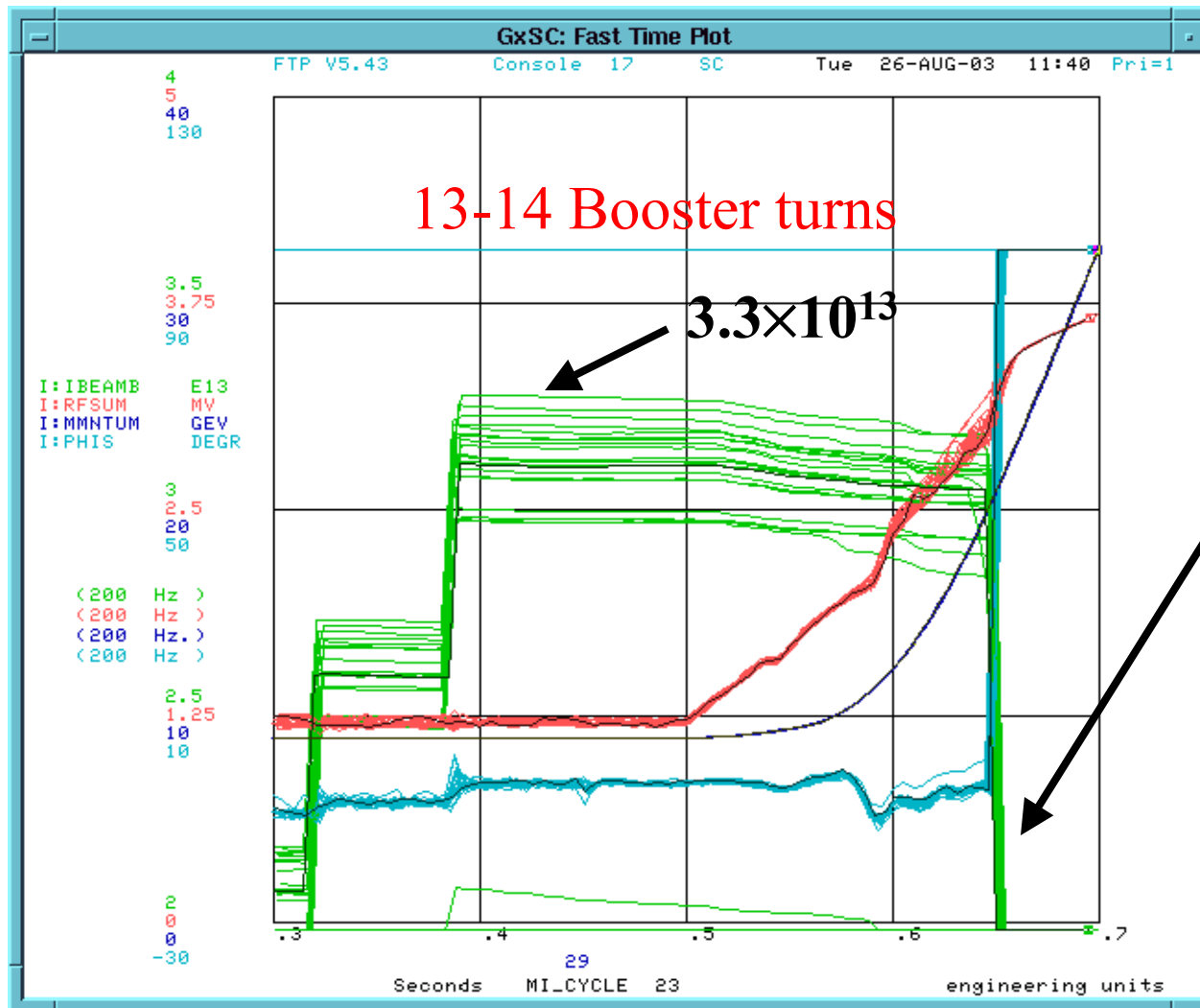**with dampers**

Pushing up the intensity…
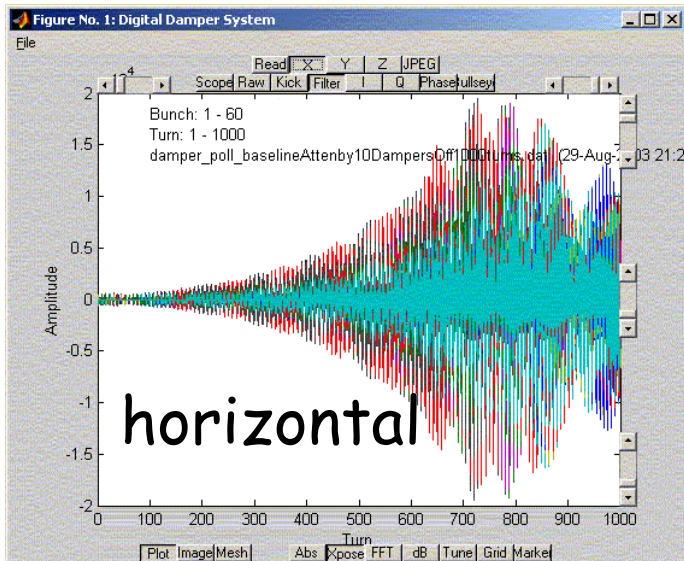

13-14 Booster turns

3.3×10^{13}

Beam extracted at 0.65 s, just before transition

What if… I turn dampers off ?

turn dampers off

intensity

horizontal

vertical
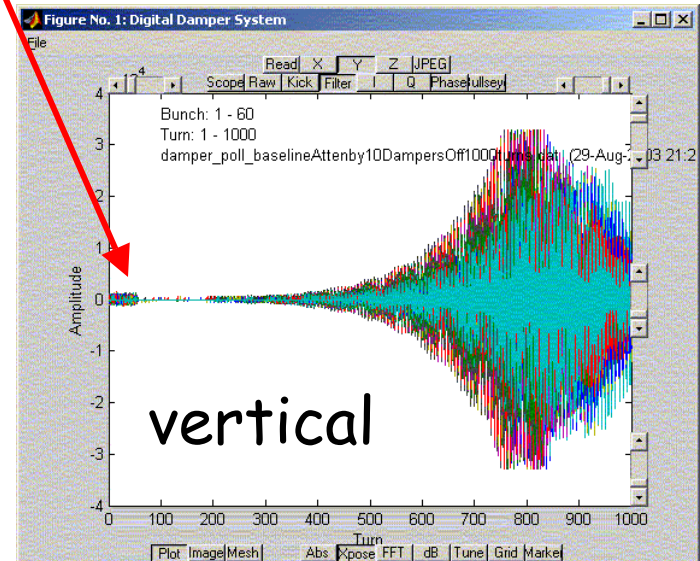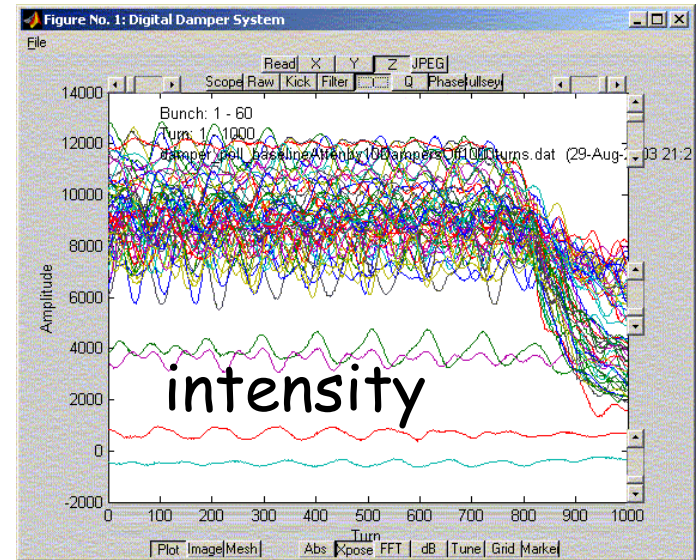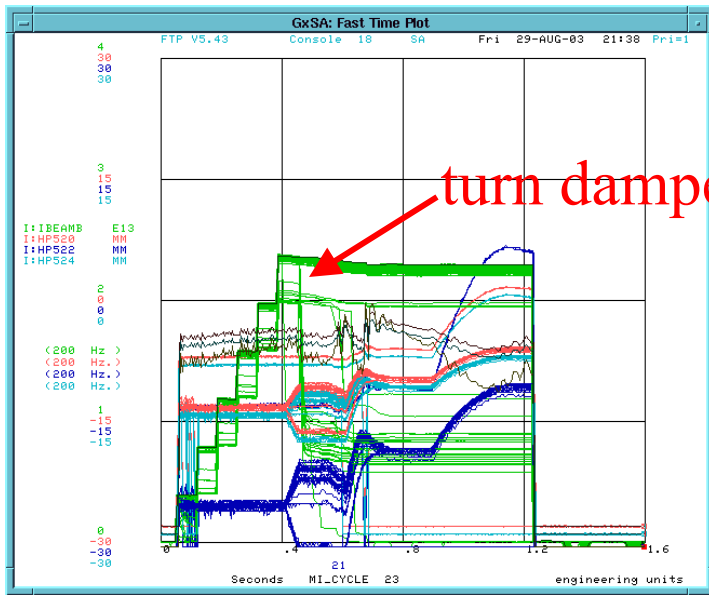
Working on dampers ...

❖ The damper system is essential to reach our goal
❖ The digitized data provides a wealth of information on the beam behaviour
❖ The display program has been recently imported into Java

Hyejoo K. (Stanford University)
➢ looking into firmware code. FPGA used only at 30%.
➢ implemented batch by batch intensity measurement, interfaced to ACNET. Accuracy ?

o **learn how to operate and optimize the damper system (transverse and longitudinal)**
o **optimization of the display program**
o **develop a tune meter (bunch by bunch), ...**
o **Expertise:** *electronics, software skills, Java language, ACNET, beam physics*

Instrumentation

We need the instrumentation to work in multi-batch operation (dynamic range issues, batch-by-batch specific measurements,…)

➢ **Measurement of beam position**

▪ the present BPM system is not working with 6 batches positioned as required by simultaneous antiproton stacking and NuMI operation

▪ batch by batch position measurements are not currently available

▪ *upgrade of the MI BPM system is foreseen to start in 2004 and be commissioned by middle of 2005*
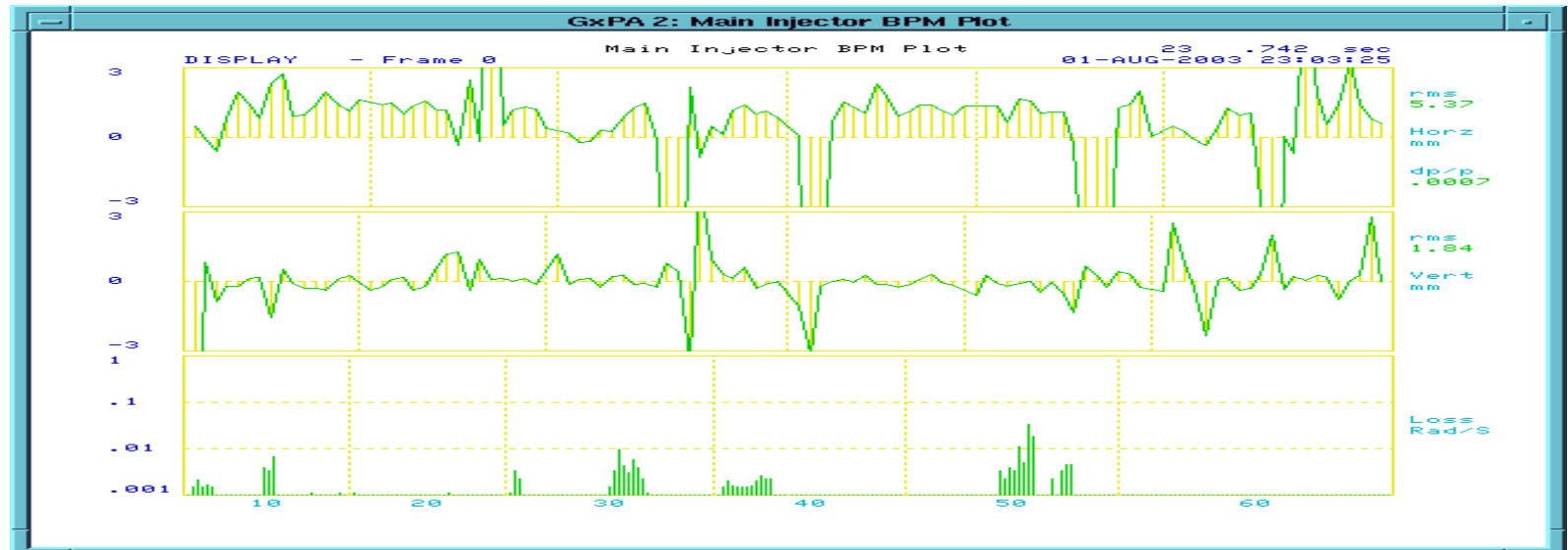
➤ **Measurement of beam intensity**

- ▪ we have instruments (DCCT, Toroids) to measure total beam intensity in MI
- ▪ presently need to understand the accuracy of batch by batch intensity measurements from the damper system

o *(Adapt the existing sampling devices of the Resistive Wall Monitor signal (Sampled Bunch Display (SBD) and Fast Bunch Integrator (FBI)) to get batch by batch intensity measurements)*

o **Intercalibrate intensity measurement devices in Main Injector**

o **Measure beam intensity in the NuMI beamline with the toroids installed there and compare to measurements in Main Injector**

o **Expertise:** *understanding of the detectors and their calibration, electronics, C language, LabView, ACNET*

➢ **Measurements of transverse emittance**

▪ **Flying wire system**: this is our primary system for emittance measurements, but in case of multi-batch operation it has to work under quite different beam conditions from current operation
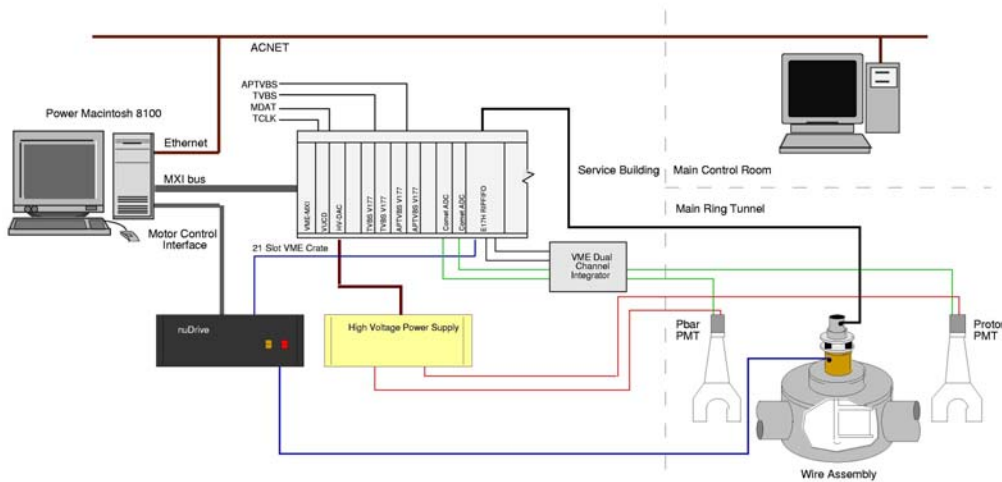

Figure 1. Single Wire Configuration.
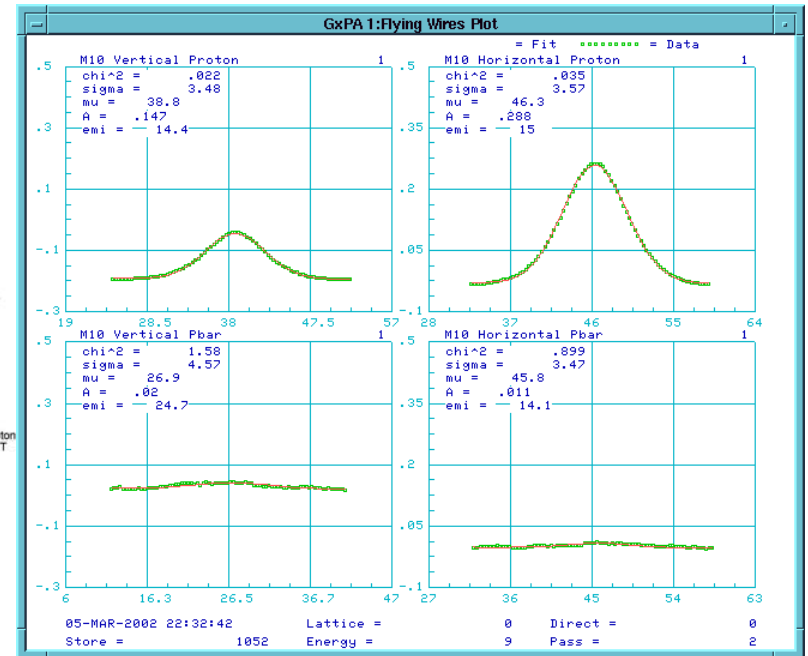
$$\varepsilon^* = \frac{6\sigma^2 \beta\gamma}{\beta_{Latt}}$$

▪ **Ionization Profile Monitor**: presently used only in a qualitative way, lacks quantitative understanding. Probably working better in multi-batch mode due to a presumably larger output signal.
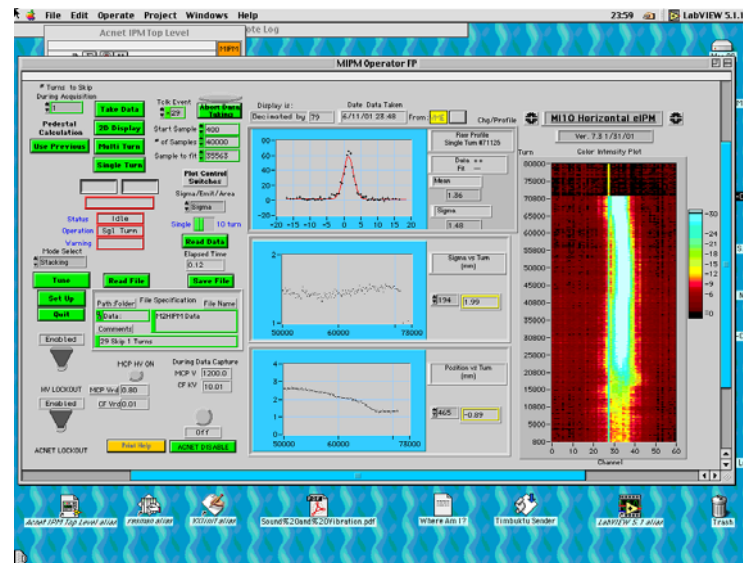
o **Understand physics principles of an IPM**
o **Use Flying Wire and IPM systems to measure transverse beam size and compare the 2 systems**
o **Expertise:** *particle detectors, electronics, LabView, analysis, beam physics*

➢ **Measurements of longitudinal emittance**   **U. of South Carolina**

  ▪ Digitization and analysis of signals from the resistive wall monitor
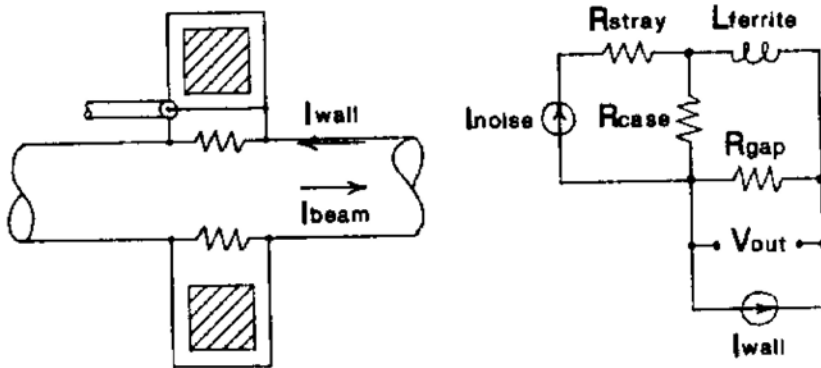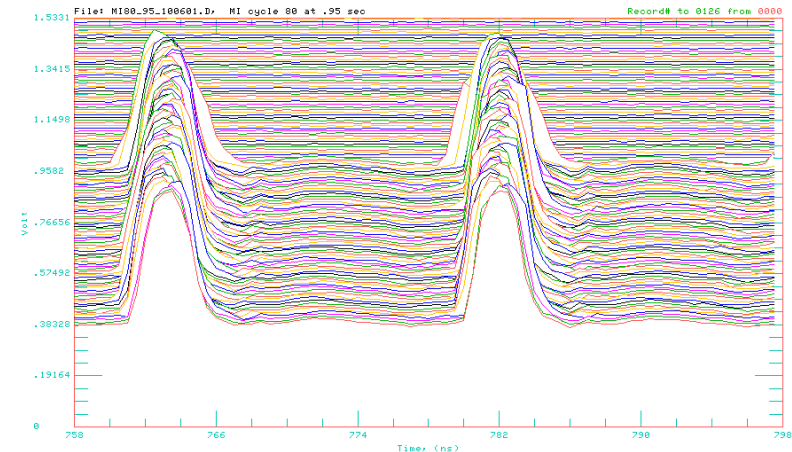

Fig. 2 Basic resistive wall monitor with equivalent circuit.

  o Provide online real time analysis of bunch intensities, widths and phases
  o Expertise: *DAQ, online systems, ACNET*

➢ **Digitization and analysis of the stripline detector signals**
  ▪ Determination of beam instabilities   **U. of South Carolina**

Longitudinal Emittance Measurements

Q.K.Wu
S.R.Mishra

8 GeV, injection into MI

Intensity (E13)	Bunchlength (4σ) (ns)	$\Delta p/p$ %	ε_ℓ (eVs)
0.22	5.0	0.16	0.11
0.71	5.22	0.16	0.12
0.94	6.12	0.19	0.16
1.3	6.52	0.20	0.18
1.5	7.26	0.22	0.22
2.1	9.24	0.27	0.34

USCHEP
University of South Carolina
High Energy Physics Group

➤ **Development of fast loss monitors**

▪ the present beam loss monitor system consists of cylindrical ionization chambers with poor time resolution, of the order of a few ms (due to electronics)

▪ it would be useful to have a system capable of measuring losses turn by turn , batch by batch, within a batch,…

▪ placing a few such detectors on the NuMI extraction Lambertsons would provide important information on extraction losses

o R&D on fast loss monitors
o build a few detectors, install and integrate them into the ACNET system
o Expertise: *particle detectors, electronics, ACNET*

Polycrystalline CdTe Detectors

- Experience at CERN with CdTe X-RAY detector
  - running in LEP for beam emittance measurement
  - was used up to the end with total dose 10^{14} Gray
- Advantages
  - large number of e- created per MIP (~5 $\times$ Diamond)
  - very fast response time
  - simple construction
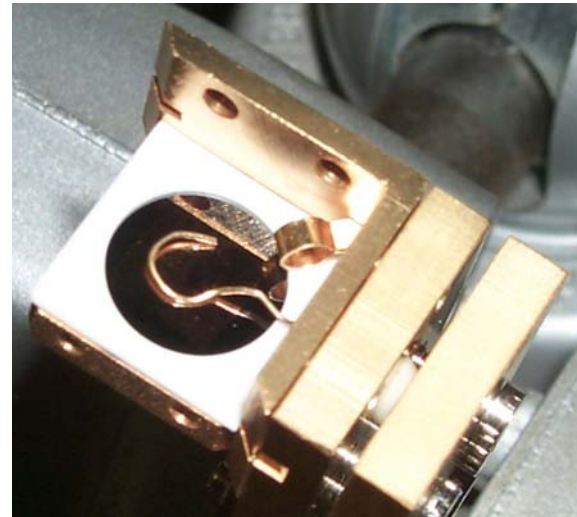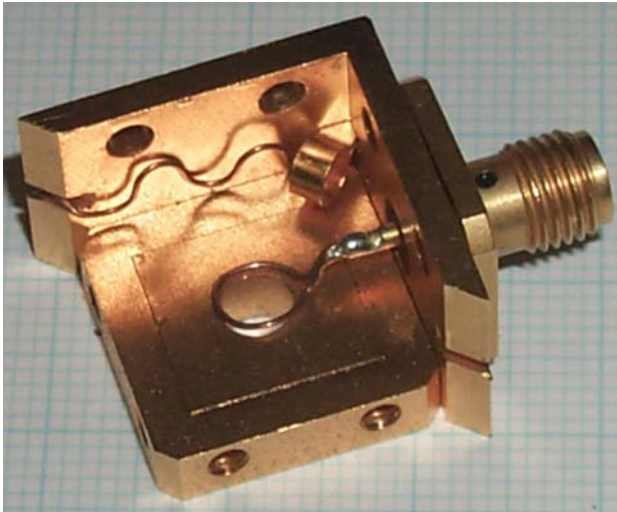
Main Injector RF system

▪ We have been having RF cavity trips during studies. The problem has been traced back to low levels for the trip limits of the anode supplies. They will be raised during the shutdown.

▪ Any fundamental problem behind it ? What is the effect of beam loading compensation on the power consumption ?

▪ How robust is the RF system ? Could we run with 1 cavity off ? And with 2 cavities off ?

Present behaviour of
RF cavities with
2.5×10^{13} protons
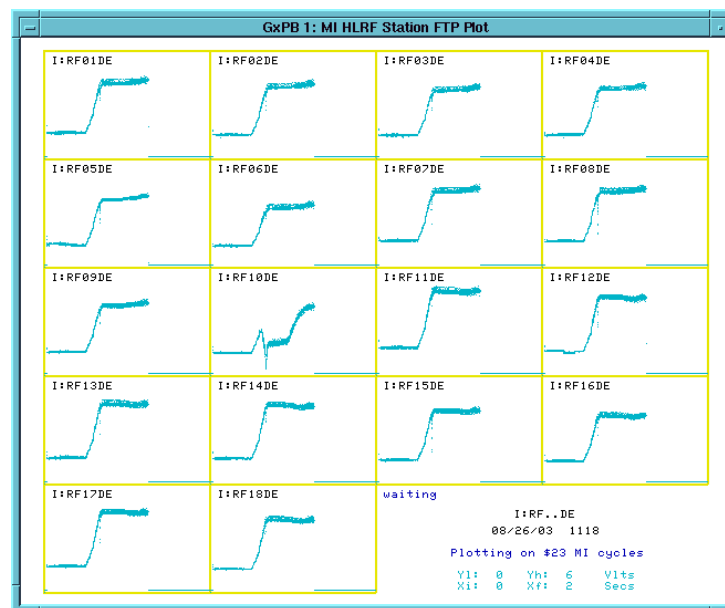
Main Injector Beam Permit for NuMI

U. of South Carolina

Andrew G., Karen W., Sanjib M.

➢ **This is required during operation (and commissioning ?) of the NuMI beamline, to avoid beam losses in the NuMI beamline due to poor quality beam extracted from MI.**

- a set of appropriate fast signals from Main Injector, indicative of beam quality, need to be identified
- a signal has to be provided to the NuMI permit system and used to abort beam extraction to the NuMI beamline when the quality criteria are not met
- we need to proceed on this ASAP, beginning to write specifications for the system

NuMI extraction region

❖ Some of the correctors in the NuMI extraction region, which will be needed to create bumps at the Lambertson positions, are currently running at high current (H608 and H612). This does not leave enough margin to create the bumps needed for the NuMI extraction. All around the ring, several correctors are running at relatively high current.

➥ Retune the closed orbit in MI, trying to reduce the current in the correctors. This might require also moving small displacements of some of the quads.

❖ Study MI orbit with Lambertson and kicker bumps

➥ what is the effect of going off-axis in the MI60 RF cavities in the last part of the cycle ?

❖ Test effect of MI52 kicker fall time on the first NuMI batch. Determine the appropriate spacing of the batches.

Operational issues

❖ Set up an operational cycle for simultaneous antiproton stacking and NuMI operation

➢ Finalize shape of magnetic ramp and LLRF batch positioning

➢ implement slip-stacking gymnastic for the batch delivered to the antiproton target, followed by the injection of 5 batches for NuMI

➢ extract the slip-stacked batch to the antiproton target and the following batches to NuMI (to the abort region for a test)

➢ study the effect of bunch rotation (required by the antiproton source) on the NuMI batches

Measurements of beam characteristics

❖ Measurements of transverse emittance and momentum spread at 120 GeV

  ➢ …easy to do if instrumentation tools work OK

○ **measurement of the central momentum of the beam at 120 GeV (now uncertain within a few 100 MeV)**
○ **Expertise:** *accelerator physics, ACNET*

Main Injector losses

❖ Main Injector beam losses
  ➢ are we going to be limited by the amount of losses in MI ?
  ➢ now probably not, but it might be a problem in the future
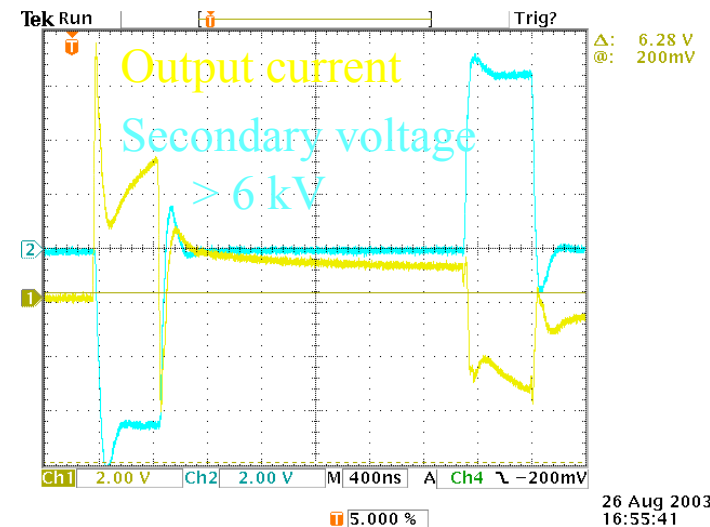❖ Main Injector shielding assessment
  ➢ from ES&H document, November 2002: "The Main Injector is sufficiently shielded to safely run with 6 bunches of 5E12 for a total of 3e13 protons/pulse at the 120 GeV 1.87 second cycle time. This cycle time would equate to an Intensity/Energy limit of 5.78E16 protons/hour" (1.6E13 protons/second).

o **get a measurement of beam losses now (both on stacking cycle and on multi-batch during studies) and extrapolate to NuMI running conditions**
o **develop a plan for a data logger system**
o **identify loss points and see how to mitigate them**
o **Expertise:** *good judgment, notions of radiation control, software skills, ACNET*

Barrier RF cavity and Stacking studies

... a Fermilab-KEK-Caltech collaboration

Hai Zheng

Output current

Secondary voltage > 6 kV

Tek Run · · · Trig?

Δ: 6.28 V
@: 200mV

Ch1 2.00 V   Ch2 2.00 V   M 400ns   A   Ch4 ⅃ −200mV

5.000 %

26 Aug 2003
16:55:41

o Barrier RF stacking and fast "Recycler" stacking studies

Cogging in the Booster

Bob Zwaska

- Notch beam intelligently
  - Anticipates slippage later in the cycle
  - Reduces spread of notch positions
- Radial Feedback after transition
  - Exponential damping
  - e-folding time $\approx$ 10 ms
  - Will become power law and get to zero
- Radial positions changes of up to about 4 mm are tolerable
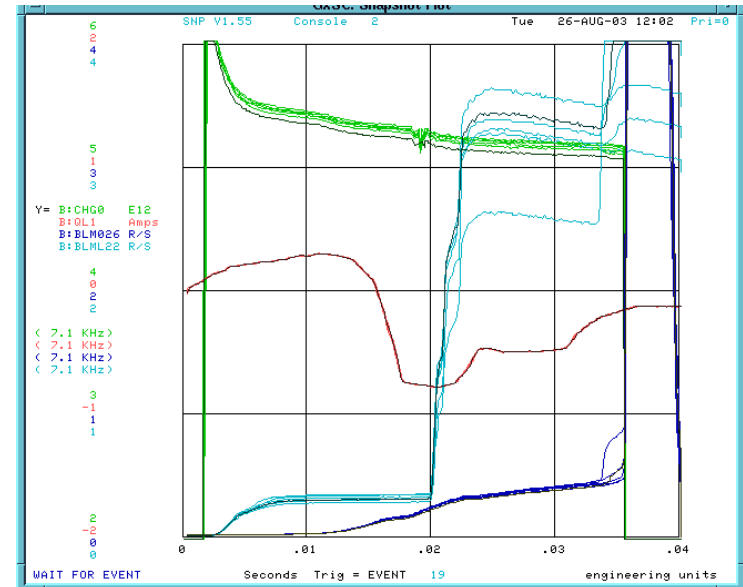- Timing errors have been eliminated, reducing slippage
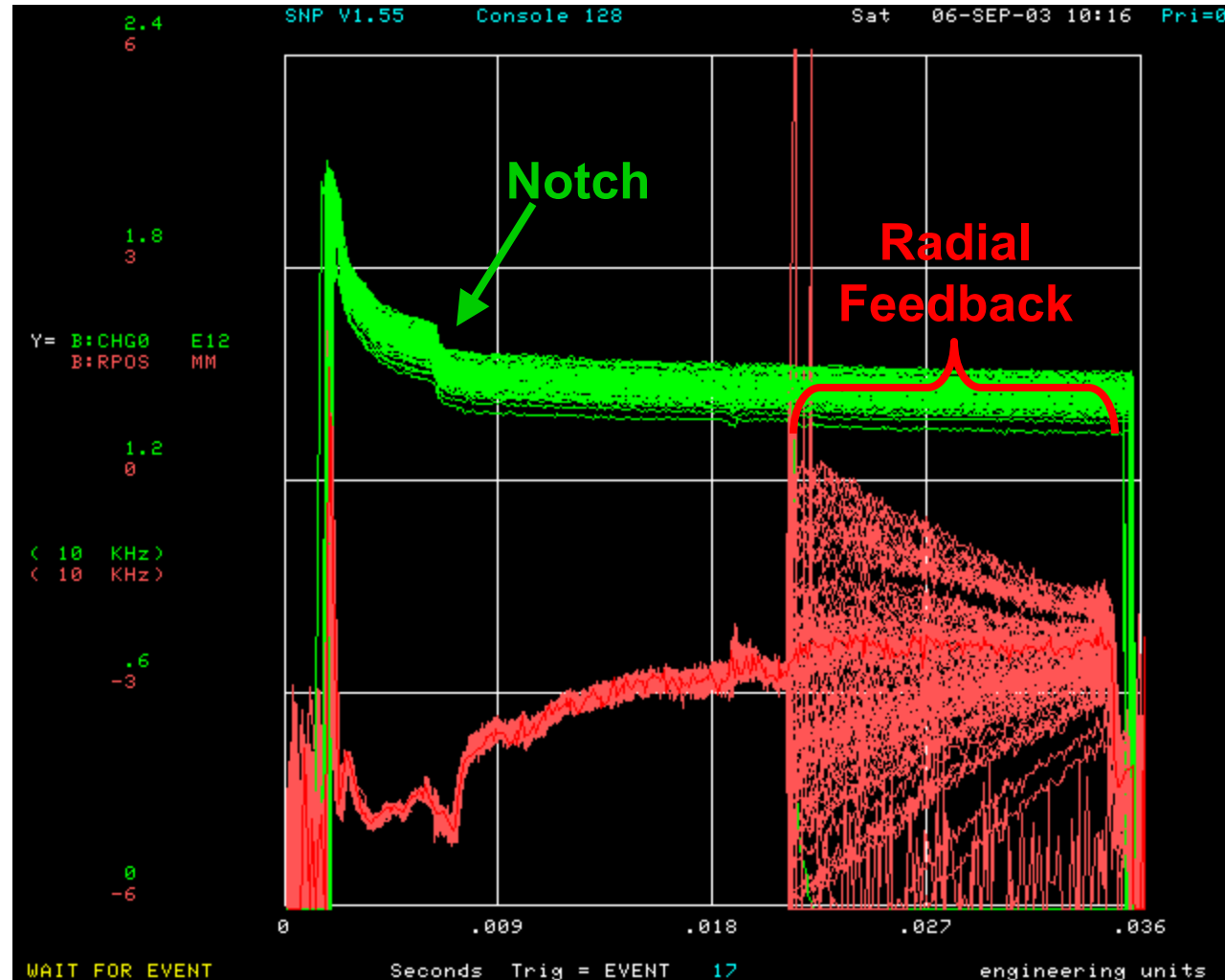
Booster losses and beam quality

Stacking Booster event
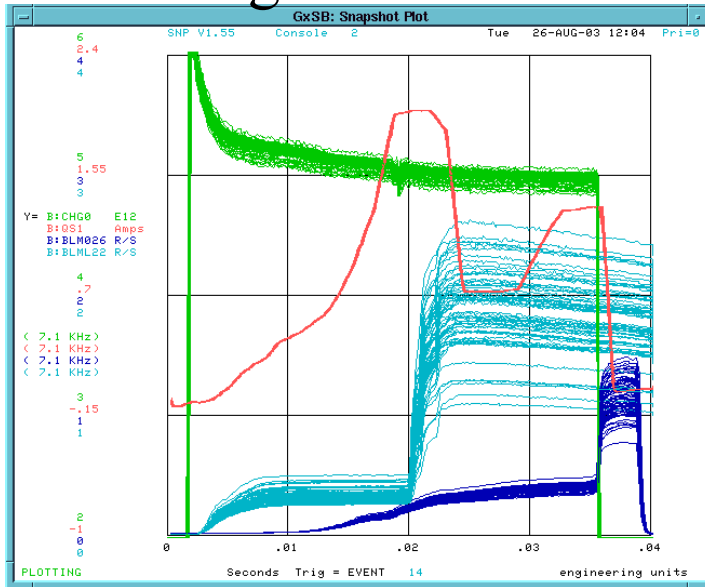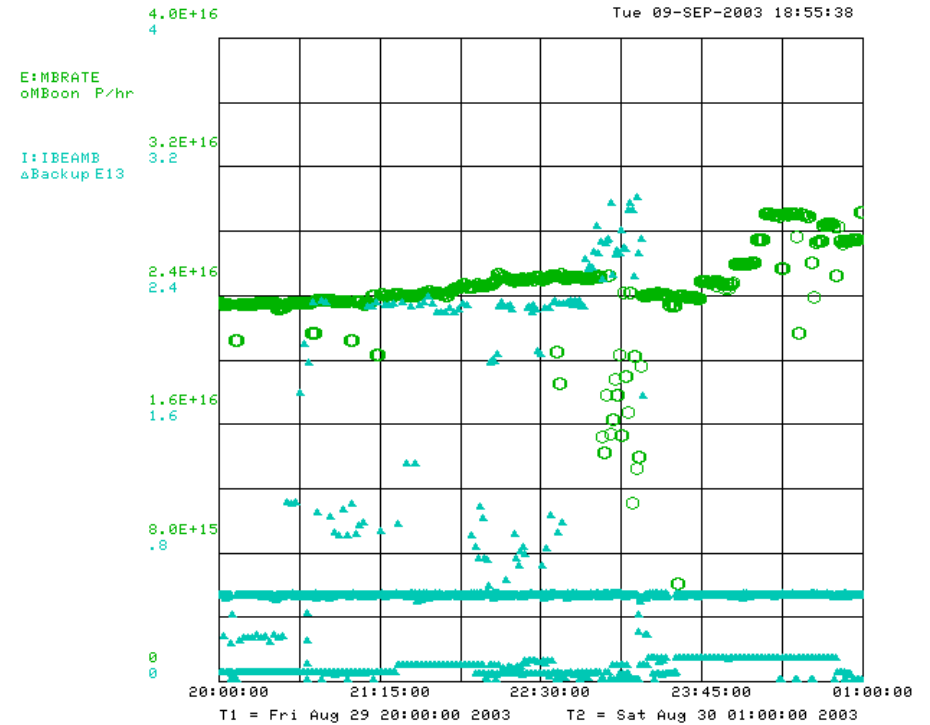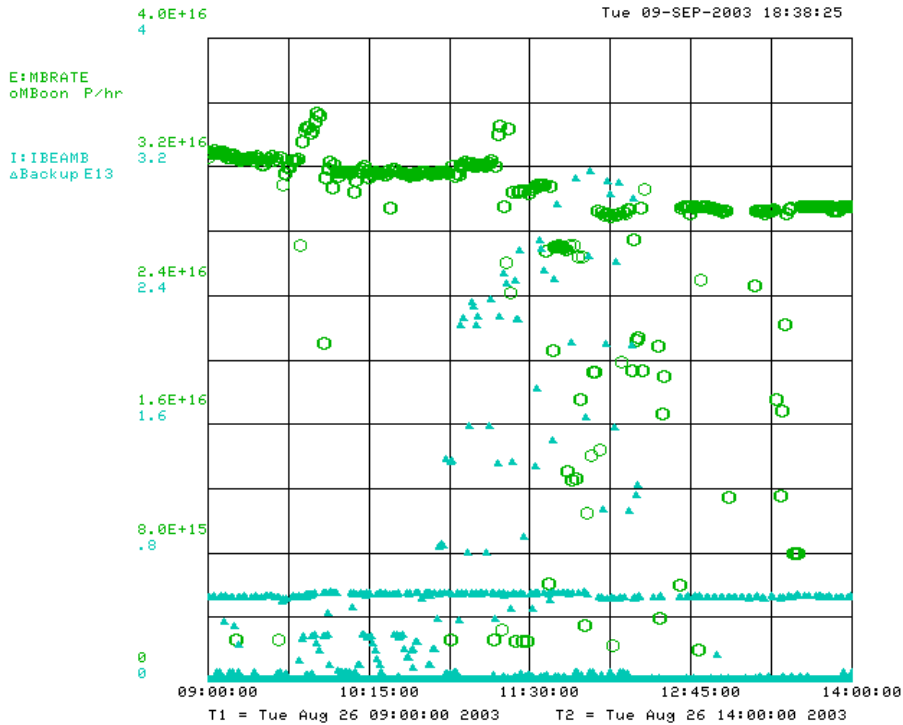

NuMI Booster event

🔔 The amount of protons to NuMI will finally depend on how well we keep Booster beam losses down

o **Understand beam losses, longitudinal dampers**
o **Measure beam quality**
o **bunch rotation**
o **Expertise:** *beam physics, ACNET*

The effect on MiniBoone ...

Conclusions

❑ My view of priorities

➢ solve the notch problem in the Booster for multi-batch operation

➢ make cycle $23 operational (orbits at extraction, batch positioning, slip-stacking, bunch rotation,…)

➢ develop a beam permit system

➢ get 3.3×10^{13} protons accelerated to 120 GeV in MI

➢ measurements of beam characteristics

➢ Barrier RF stacking and fast "Recycler" stacking studies

The present help is very much appreciated
We need more help …
Begin with **http://www-numi.fnal.gov/workgrps/protonwg/techdocs.html**